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A History of Flow Simulation Studies at St. Andrews Biological Station

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A HISTORY OF FLOW SIMULATION STUDIES AT ST. ANDREWS BIOLOGICAL STATION

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ABSTRACT

Wildish, D. J. 1991. A history of flow simulation studies at St. Andrews Biological Station. Can. Manuscr. Rep. Fish. Aquat. Sci. 2134: iii + 25 p.

An historical perspective of flow studies at the St. Andrews Biological Station is presented with emphasis on the equipment used. Flow simulators, inclusive of flumes, growth tubes or respirometers, were either originally designed or taken from literature sources and built for specific experimental purposes. Six flow simulators built or used in the period 1981-91 are described and their purpose, capabilities and characteristics are discussed. The flow simulation lab, 1991 vintage, is described in detail inclusive of ways used to measure environmental variables (velocity, seston concentration and temperature) during an experiment, how the data are collected, stored and analyzed. Possible improvements to the lab are also discussed.

RÉSUMÉ

Wildish, D. J. 1991. A history of flow simulation studies at St. Andrews Biological Station. Can. Manuscr. Rep. Fish. Aquat. Sci. 2134: iii + 25 p.

Ce document trace l'historique des études de débit réalisées à la station biologique de St. Andrews, en insistant sur le matériel utilisé. Les simulateurs de débit, comprenant des canalisations, des tubes de culture ou des respiromètres, ont été conçus à partir de zéro ou encore construits aux fins expérimentales spécifiques selon des modèles provenant de sources documentaires. Ce document décrit six simulateurs de débit, construits ou utilisés de 1981 à 1991, et explique leurs objectifs, leurs capacités et leurs caractéristiques. On y décrit en détails le laboratoire de simulation du débit, version 1991, y compris les méthodes utilisées pour mesurer les variables écologiques (la vélocité, la concentration de seston et la température) au cours d'une expérience. On décrit aussi comment les données sont recueillies, emmagasinées et analysées et on discute des possibilités d'améliorer le laboratoire.

INTRODUCTION

It is fitting that tidal energy as a key environmental variable should be studied at the St. Andrews Biological Station. St. Andrews is situated at the mouth of the Bay of Fundy - a macrotidal estuary reputed to have one of the largest tidal ranges in the world. The tremendous tidal energy dissipated within the Bay has resulted in various attempts to harness it as a renewable source of electrical power. This began in the 1920's when Passamoquoddy Bay was the focus (Huntsman 1952) and again in the 1970s at many possible locations, with a favored option being the upper Bay - Chignecto Bay or Minas Basin (Daborn 1977; Gordon and Dadswell 1984). Economic factors forced abandonment of the tidal power project on each occasion, although in 1984 a small demonstration tidal power facility was installed at Annapolis Royal. This 17.8 MW capacity plant on the Nova Scotia shore is still in operation today. As the supply of fossil energy diminishes, the Bay of Fundy tides may again be considered as a source of electrical power for the Maritimes.

Early in the twentieth century many invertebrate fisheries biologists had noticed that bivalve molluses grew faster, or larger, where seawater tidal currents were more rapid (e.g. Belding 1912; Fraser and Smith 1928; Kerswill 1949). The latter author, Dr. C. J. Kerswill, worked at the St. Andrews Biological Station first as a student (1938-41) doing bivalve graduate studies at the University of Toronto. Later he was employed at the Station (1942-46) as a bivalve biologist, returning for a second period (1949-63) as principal scientist in charge of salmon investigations. Jim Kerswill conducted some original field experiments to test the effect of "water circulation" on growth of quahaugs (*Mercenaria mercenaria L.*) and oysters (*Ostrea virginica L.*). This work was done near the Biological Station, Ellerslie, Prince Edward Island in 1939-40. The results (Table 1) clearly show that water circulation affects the growth rate of both bivalves over a summer-fall growing period, although direct measures of velocity or volumetric flow were not available. In tray experiments with sediment, the growth of quahaugs was reasonable with growth limitation $\leq$ 0.8 m above

Table 1. C. J. Kerwsill's 1940 field experiments with quahaugs in trays (73 animals per tray) 60 x 120 cm with 15 cm sides, filled with sand or oysters, and quahaugs in boxes 60 x 11 cm with 30 cm sides. Each box was divided into 3 layers with 1.25 cm galvanized wire with 10 cm depth between each. Two compartments (60 x 45 cm) were present in each layer with 73 quahaugs in one and 75 oysters in the other.

Type of equipment	Height above sediment-water interface m	Initial mean height ± SE mm	Final mean height ± SE mm	Growth mm	Specific growth $\frac{L_1-L_0}{L_0}.100$
Trays with sediment and quahaugs	2.3	31.4 ± 0.6	40.4 ± 0.5	9.0	28.7
	1.5	31.0 ± 0.7	39.6 ± 0.6	8.6	27.7
	0.8	31.8 ± 0.7	39.2 ± 0.6	7.4	23.3
	0	30.8 ± 0.9	38.1 ± 0.6	7.3	23.7
Boxes with quahaugs only	Box openings				
	Open end	31.1 ± 0.8	35.7 ± 0.6	4.6	14.8
	Slatted ends	30.8 ± 0.8	34.3 ± 0.5	3.5	11.4
	Solid end/few holes	31.6 ± 0.7	33.0 ± 0.6	1.4	4.4
Boxes with oysters only	Box openings				
	Open end	24.7 ± 0.3	48.9 ± 0.7	24.2	98.0
	Slatted ends	24.7 ± 0.3	47.6	22.9	92.7
	Solid end/few holes	24.7 ± 0.3	28.1	3.4	13.8

the sediment, suggestive of benthic boundary layer limitation. In boxes lacking sediment but containing quahaugs, growth was much less because they grow poorly unless properly burrowed into the sediment. By contrast, oysters grew extremely well on wire mesh, although the flow-limited oysters (solid end/few holes) were also slow growing. In the latter case, the cause of growth limitation was almost certainly due to seston depletion and starvation as 34 of the 75 oysters died during the experiment. These, and similar, experiments confirm that some bivalve populations grow faster when exposed to higher velocities, but do not explain why.

In 1971, a large hydraulic flume was constructed at the St. Andrews Biological Station. It was of wood with acrylic viewing windows and two side-by-side, 15-m long channels. One channel was 119 cm and the other 92 cm wide with wall heights of ~120 cm. Flow was conditioned at either end of the channel where dividers were absent, and included two, low-speed propellors to recirculate water at velocities up to 150 $cm \cdot s^{-1}$. The flume was used in the development of underwater instruments by the Fishing Gear Engineering research section and in simulating juvenile salmon stream habitats at 50-70 $cm \cdot s^{-1}$ for studies involving territoriality and feeding (Symons 1973). This flume was dismantled in 1979.

My own interest in tidal energy as a key variable in benthic ecology grew with a study of L'Etang inlet beginning in 1970. The primary purpose of this work was to document the benthic effects of organic pollution by pulp mill wastes discharging into the upper L'Etang. One could not avoid noticing the dominant effect of tidal velocities in the shaping of functional groups of benthic animals found there. With a change in direction of my work to determine the benthic biological effects of the previously mentioned 1970's tidal energy project (Wildish 1977a) and a chance to attend an international conference, which required a publishable manuscript, the moment was right to marshal ideas on tidal currents and benthic ecology. The conference was organized by Dr. Otto Kinne (International Helgoland Symposium "Ecosystem Research") and took place on the island of Helgoland from 26 September-1 October 1976. The paper presented (Wildish 1977b) hardly aspired to the ecosystem level of the conference, since it was limited to subtidal sediments. A publication list including all flow-related work published since, inclusive of papers in preparation to the end of 1991, is shown at the end of the Reference list.

Professor David D. Kristmanson of the Chemical Engineering Dept. of the University of New Brunswick, who had collaborated with me in the L'Etang work, also became interested in tidal velocity as a control for suspension feeding macrofauna. Professor Kristmanson has contributed a detailed knowledge of the physics of flow and an ability to represent complex ideas in terms of mathematical formalism to our joint work. My own thinking is visual and literate and has caused an interaction which is aptly described in a poem by Robert Graves (1961):

In Broken Images

He is quick, thinking in clear images:
I am slow, thinking in broken images.

He becomes dull, trusting to his clear images;
I become sharp, mistrusting my broken images.

Trusting his images, he assumes their relevance;
Mistrusting my images, I question their relevance.

Assuming their relevance, he assumes the fact;
Questioning their relevance, I question the fact.

When the fact fails him, he questions his senses;
When the fact fails me, I approve my senses.

He continues quick and dull in his clear images;
I continue slow and sharp in my broken images.

He in a new confusion of his understanding;
I in a new understanding of my confusion.

David Kristmanson was also largely responsible for the design of two of the flow simulators (#1 and #3) used in experimental work (see Table 2).

It is the purpose here to present a brief description of the flow simulators used in 1981-91, their design, purpose and limitations. Also presented is a description of the flow simulation lab as it existed in 1991, with a discussion of some possible future developments.

Table 2. Flow simulators built or used in the period 1981-91 at the St. Andrews Biological Station

Simulator number	Name	Type	Volume capacity L	Reference
1	Single channel flume	Flow-through	FULL - 1125 20 cm depth - 500	Wildish and Kristmanson (1984)
2	Kirby-Smith growth tube	Flow-through	1 tube - 165 8 tubes-1319	Kirby-Smith (1972) Wildish and Kristmanson (1985)
3	Multiple channel flume	Flow-through	FULL - 1670 20 cm depth - 740	Wildish et al. (1987) Wildish and Kristmanson (1988) Wildish and Saulnier (in press)
4	Blažka respirometer	Re-circulating	50	Bearnish (1978) Wildish et al. (1987)
5	Modified Vogel flume	Re-circulating	90	Vogel (1981) Wildish and Miyares (1990)
6	Mini Flow Tank	Re-circulating	200	Saunders and Hubbard (1944)

FLOW SIMULATORS, 1981-91

Six flow simulators were built or used at the Biological Station (Table 2) in the 10-yr period ending in 1991. Other flow simulators proved to be unsuitable and were discarded (e.g. Appendices 1 and 2).

1) SINGLE CHANNEL FLUME

The first flow simulator to be built was made with marine, resin-coated, plywood by the Station workshop (Fig. 1). Its purpose was to determine whether or not a seston depletion effect could occur downstream of a mussel bed. The flume was deployed on the shore side of the main building at the top of the intertidal region, was provided with a roof for weather protection, and had working section dimensions of 5 m x 0.5 m. Unfiltered seawater was pumped by a 4 H.P. submersible pump located just above bottom near the wharf. The maximum flow possible was ~ 5 $cm \cdot s^{-1}$. Velocity measurements were made with an hydrogen bubble generator apparatus, or volumetrically with a simple orifice meter and water manometer. This flume was eventually given to Kee Muschenheim of the Dept. of Oceanography, Dalhousie University, and transported there aboard the R/V ALFRED NEEDLER. This was near the beginning of Kee's graduate studies and must have provided a stimulus to build a better flume (see Muschenheim et al. 1986).

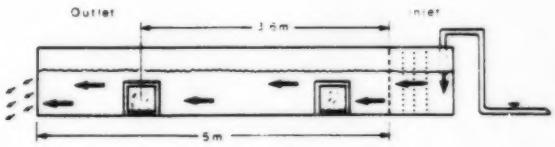

Fig. 1. Single channel flume #1.

2) KIRBY-SMITH GROWTH TUBE

For longer-term measures of the growth rate of bivalves, Kirby-Smith (1972) designed a growth tube apparatus which was used in our studies of giant scallop growth (Wildish and Kristmanson 1985). The construction of the headtank and outflow boxes was of marine plywood in the Station workshop (Fig. 2). Seawater supply to the constant head tank was from the same pump as used for the single channel flume. Experimental bivalves were supported in the centre line of the 1.5-m long acrylic tubes by plastic mesh inserts. Bulk flow velocities were determined from timed volumetric flows divided by the area of tube cross section (=38.47 cm^2) thus:

$$\text{bulk flow velocity, } cm \cdot s^{-1} = \frac{\text{volumetric flow rate, } cm^3 \cdot s^{-1}}{38.47}$$

Pipe flows are complex with maximum velocities at the pipe centre line where velocities, when fully developed, are 2x the mean, or bulk, velocity. Thus bulk velocities underestimate velocities experienced by bivalves at the tube centre line. Although it is possible to insert velocity probes through the tube walls in rubber bungs, this was not done during our experiments (Wildish and Kristmanson 1985).

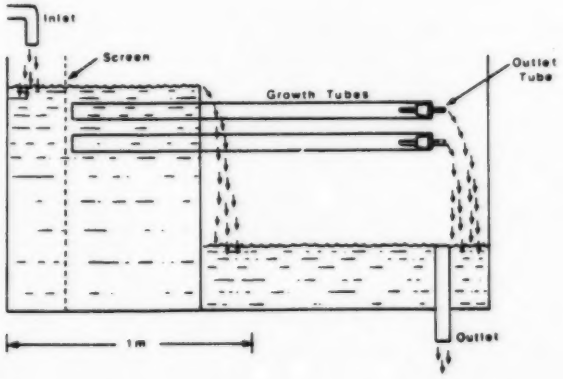

Fig. 2. Kirby-Smith growth tube apparatus #2.

3) MULTIPLE CHANNEL FLUME

In using unfiltered seawater in bivalve growth studies, velocity as the primary variable can only be compared within each experimental run. This is because seston concentration and quality will be variable for consecutive experiments. The four channels of the multiple-channel flume which are run concurrently thus mean that four treatments at the same seston concentration (and quality) can have varying velocities (versus eight in the Kirby-Smith growth tube).

The multiple channel flume (Fig. 3) was built in the Station workshops from a design by D. D. Kristmanson. It occupies a semi-permanent position near the Biological Station tide pool and is protected from weather by a wooden building which is wired for electrical power. The working part of the flume is 5 m long with a downstream flare (from 64-85 cm wide). The flume is divided by plywood walls into four equal channels, each 15 cm wide at the inlet, and 20 cm wide at the outlet end. The seams of the channels were caulked to prevent seawater exchange between them. Velocities in each channel could be adjusted by removing rubber bungs in a perforated bulkhead which terminated the working section (Fig.3). Originally, the unfiltered seawater for the flume was supplied by a separate 3" line and 8 H.P. submersible pump located near the wharf. A maximum flow of ~15$cm \cdot s^{-1}$ in one of the flume channels was possible with this arrangement. More recently, unfiltered seawater for the multiple channel flume has been supplied direct from the small reservoir from the main seawater supply before it passes through a sand filter.

One advantage of the multiple-channel flume over the growth tube in that it permits a more realistic simulation of flow with a flume boundary layer present during the experiment. The flume also allows better access to determine velocity profiles near the experimental bivalves, e.g. with a Nixon Stream Flo probe (see p.11).

4) BLAŻKA RESPIROMETER

With flow-through devices, designed to measure bivalve growth, it is practically impossible to adjust the seston concentration and quality. This is because of the large volumes involved and great cost in providing sufficient amounts of cultured microalgae. Thus, for instance, in the multiple channel flume, the volumetric flow required would be 444 L/min at a modest flow of 5 $cm \cdot s^{-1}$ and flume depth of 20 cm. In order to examine velocity concurrently with seston concentration and quality, it was necessary to minimize the volume of seawater

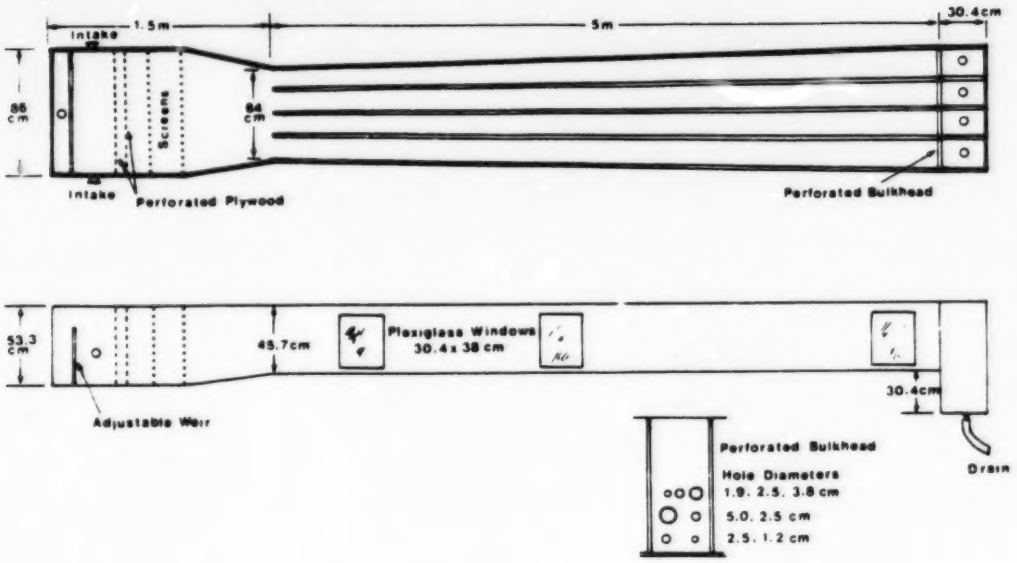

Fig. 3. Multiple channel flume #3. Top - plan view; bottom - elevation view.

used and to employ a recirculating system. Such an approach dictates that only short-term experiments are feasible. This is because of the buildup of excretory products in seawater with time, and hence a short-term measure, feeding, rather than growth rate, is the method of choice.

A closed, recirculating device, the Blažka, Volf and Cepala respirometer (see in Beamish 1978), became available from the Biological Station laboratory of Dr. R. W. Saunders. The Blažka respirometer consisted (Fig. 4) of an inner and outer acrylic tube with machined end walls of acrylic to maintain smooth flows. The impeller was positioned in the inner tube and caused a return flow in the outer tube. The respirometer had been constructed in the University of Toronto Workshop and could reach a velocity ~75 $cm \cdot s^{-1}$. The apparatus was designed for swimming performance experiments with fish (see also Smit 1965) and was not ideal for bivalves. The chief difficulty was that without further modification it was impossible to measure velocities near the animals which were supported in our experiments (Wildish et al. 1987) on plastic mesh in the mid, centre line of the fish chamber. A Nixon streamflo probe could be inserted through the sampling tube at one end of the apparatus (Fig. 4) but was distant from the bivalve experimental subjects.

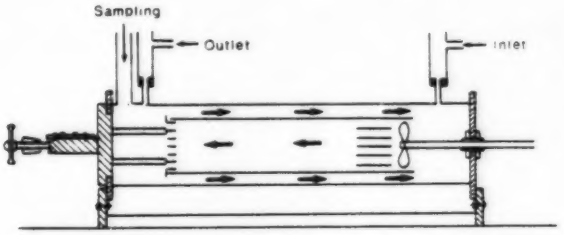

Fig. 4. Blažka respirometer #4. Redrawn from Smit (1965).

5) MODIFIED VOGEL FLUME

The flow pattern in the Blažka respirometer was that of a pipe, unlike the boundary layer flow that bivalves would experience in the natural environment. Consequently a design was sought which could provide a flume boundary layer environment. The flume design chosen was from Vogel (1981). The St. Andrews Biological Station version was constructed of 6" diameter plastic plumbers pipe and corner ells with 82 x 18.5 x 15 cm working section of acrylic (Fig. 5). Instead of mounting the propeller in the vertical position as in Vogel (1981), it was mounted horizontally with a drive shaft sealed into the lower section of the flume.

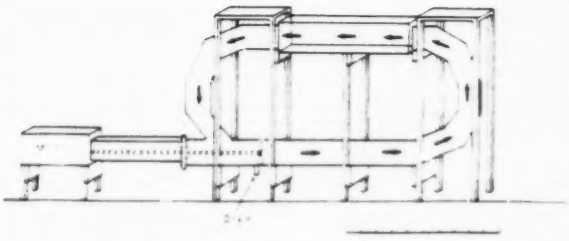

Fig. 5. Modified Vogel flume #5.

The motor was of 3/4 H.P. capacity (Leeson DC permanent magnet motor Model C4D17FK3C) and was adjusted by a Motor Master 100 rheostat. In practice this flume was satisfactory up to a flow velocity of <40 cm•s^{-1} but beyond this, entrainment of air bubbles and wave formation limited its usefulness. The flow profiles in this flume were not uniform.

6) MINI FLOW TANK

The requirement in feeding/growth studies with bivalves to provide ambient flow conditions >75 cm•s^{-1} led to a further search for a recirculating flume capable of these flows. Mr. Mark Chin-Yee, Head of the Mechanical Engineering group at the Bedford Institute of Oceanography located a reference (Saunders and Hubbard 1944) from which it appeared possible to achieve this. The flume is of cast acrylic throughout and was constructed by Plastics Maritime Ltd, Armdale, NS, according to a detailed design prepared by Mark Chin-Yee. The mini flow tank (Fig. 6) differed from the Vogel flume in having a trap from which entrained air bubbles were removed by vacuum suction, and a collimator and throat section for flow forming at the entrance to the 65 cm long by 23 cm wide working section. A different method of driving the impeller was also used - a pneumatic system with an air compressor and pressure storage tank located in a separate building. This arrangement minimized electrical noise and hence interference with acoustic methods used in the laboratory to determine animal physiological or behavioral responses.

The initial calibration results (Table 3) show that ~75 cm•s^{-1} could be achieved. With a few minor changes to the angle of attack of the turning vanes near the impellor shaft, which was shedding air bubbles, this was improved to ~100 cm•s^{-1}. Impeller settings at low velocities were not reproducible - this might be improved by use

Table 3. Mini Flow tank calibration on 31 July 1991 using Stream Flo probe #1330 positioned 8.5 cm above the flume floor.

Impellor Settings -turns	Mean Velocity cm•s^{-1}	Observations
$^1/_4$	20	clear
$^1/_2$	25	"
$^3/_4$	30	"
1	35	"
$1^1/_4$	39	"
$1^3/_4$	45	"
$2^1/_4$	55	"
$2^3/_4$	62	"
$3^1/_4$	74	Few bubbles
$3^3/_4$	93	Many bubbles

of a variable pitch propellor. Stream Flo probe profiles in vertical (Table 4) and horizontal (Table 5) planes show that velocities are uniform with a slight tendency to be less near the centre (presumably because of lower acceleration forces there than near the throat walls). Flume boundary layers on walls and floor are compressed to within 2 cm or less and flows here can only be resolved with thermistor bead velocimeter observations. A satisfactory flume boundary layer of ~8 cm high can be simulated by placing a 1-cm diameter acrylic cylinder across the entrance to the working section.

HYDRODYNAMIC CONSIDERATIONS

Ambient velocities in the Bay of Fundy for 1978 ranged from Umax = 40-150 cm•s^{-1} (see in Wildish and Peer 1983) and are complex, interacting in shallow water with wind/wave effects. In simulating these flows in the lab it has been necessary to simplify so that in all of the devices described here only a unidirectional flow was created. In only three of the simulators (the single channel flume #1, multiple channel flume #3 and Mini Flow Tank #6) has a reasonably well developed boundary layer been simulated within the working section. Thus the flume boundary layer at the downstream end of the working section of flumes 1 and 3 with adequate roughness (consisting of live or dead mussel beds) was >20 cm in height. These flumes could

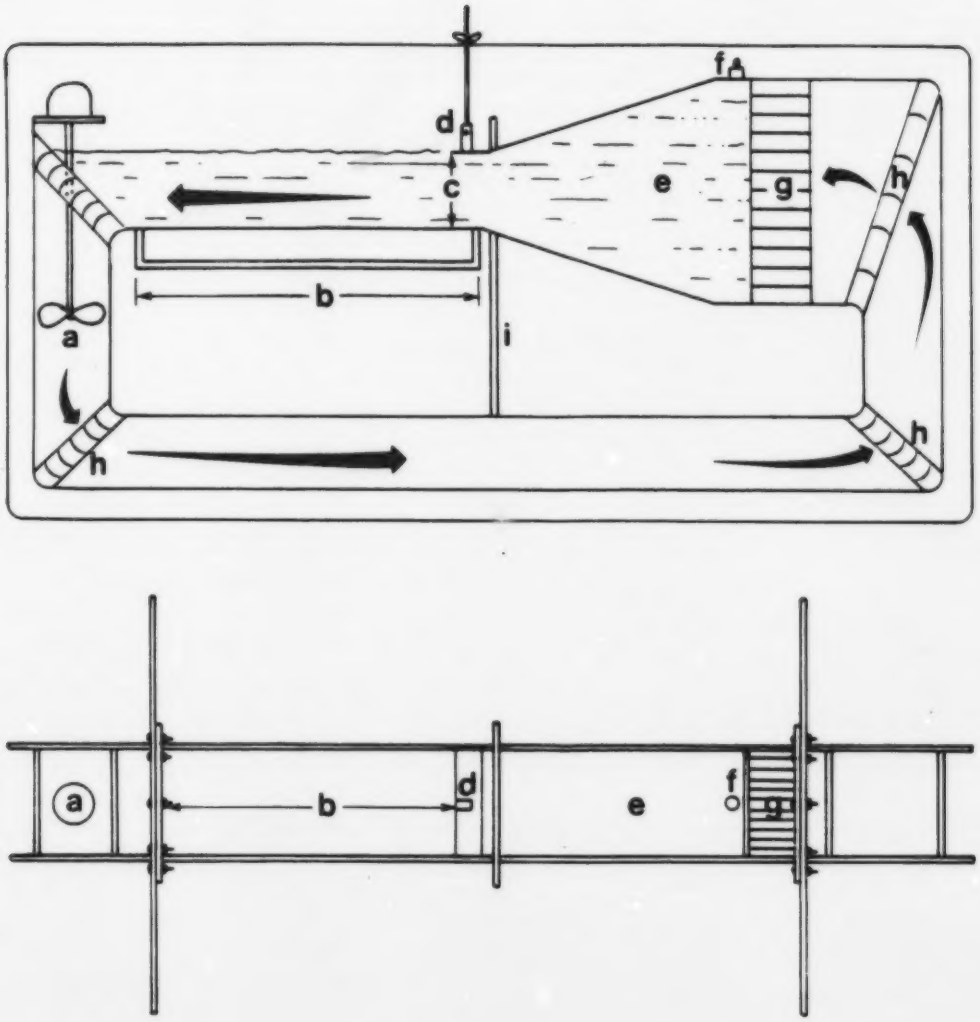

Fig. 6. Mini Flow Tank #6. a. propellor; b. flume working section with false floor; c. flow depth; d. flap for controlling surface flow; e. throat section; f. exit hole for air removal; g. collimator; h. turning vanes.

Table 4. Mini Flow Tank vertical flow profiles observed with streamflo probe #1330 on 1.8. 1991. Average of six replicated samples (10-s integrations) as $cm \cdot s^{-1}$. The probe samples 2.5 mm above bottom and since the rotor diameter is 11.6 mm the lowest sample is (11.6 + 2.5)/2 = 7.1 mm above bottom. The probe is positioned in the flume centre line at 35 cm in from the entrance.

Distance from bottom cm	Compressed air control		
	1/4 turn	2 turns	3 turns
0.7	19.9	50.9	69.9
1.7	20.2	51.5	71.6
2.7	19.9	-	69.3
3.7	19.8	49.9	67.6
4.7	19.5	48.8	66.1
5.7	19.5	-	65.4
6.7	19.4	47.2	-
7.7	-	-	64.5
8.7	19.6	47.7	66.2
9.7	20.0	-	68.1
10.7	20.8	48.9	69.1
11.7	20.7	-	-
12.7	21.2	50.5	71.9
13.7	21.6	50.4	72.5

Table 5. Mini Flow Tank horizontal flow profile at 8.7 cm above bottom and 35 cm in from the entrance as $cm \cdot s^{-1}$. Stream Flo probe #1330 measurements (average of six 10-s integrations). Flume width = 23 cm.

Distance from wall, cm	Compressed air controller		
	1/8 turn	1 3/4 turn	3 turns
0.7	17.9	47.9	67.8
1.7	17.6	47.0	67.7
2.7	17.7	47.7	67.2
3.7	17.7	46.31	68.3
4.7	17.5	47.2	68.5
5.7	17.5	47.1	68.4
6.7	17.2	48.7	69.1
7.7	17.2	48.2	68.4
8.7	17.3	48.3	67.4
9.7	-	-	-
10.7	16.9	45.5	67.7

meet the exacting requirements detailed by Nowell and Jumars (1987) for studies involving seston distribution and capture by bivalves or in determining the initial motion conditions for suspending sedimentary particles.

The two pipe flow devices (#2 and 4) have complex flows with wall drag dominating and maximum flows at the centre line where the experimental subjects were positioned during experiments.

As long as the actual velocities near the bivalve inhalant can be measured and the velocity conditions replicated then the Mini Flow Tank method is satisfactory for bivalve feeding, and single and multiple channel flumes for bivalve growth studies.

An open channel solution in a relatively small recirculating flume (<200 L volume) was sought because of ease in placing velocity measuring probes. The first attempt - a modified Vogel type flume - produced non-uniform flows at 10-15 $cm \cdot s^{-1}$ and a flow maximum of <40 $cm \cdot s^{-1}$ before air bubbles appeared in the flow. The flume conditions are influenced by the poor design for both entrance and exit conditions which do not reduce the instabilities introduced by the impellor blade stroke and in forcing the flow around four corners. Air may be entrained at either end of the flume depending on which way the flow is directed. The latest flume (#6) has a much more uniform flow profile in the working section with boundary layers on walls and floor of <2 cm thick. The entrance conditions included a collimator and throat section which effectively smoothed the flow in the working section. Cavitation caused by the revolving impellor resulted in an upper useful limit of ~100 $cm \cdot s^{-1}$.

FLOW SIMULATION LABORATORY IN 1991

GENERAL

A new laboratory was built at the south end of the Solarium wing of the Main Building. The floor plan is shown in Fig. 7. The lab includes a control room with two 1 x 1 m, one-way glass windows for viewing the wet lab., or flume room which is supplied with cold, filtered seawater, cold fresh water and air. A separate supply line is connected to a 1000-L capacity round tank situated on the floor above the lab and is supplied with filtered or unfiltered seawater with a cooling device (Mini-cool) for temperature control. Its purpose is to rapidly fill the flumes including the 1000-L capacity Maxi Flow Tank planned for installation in 1992.

The wet lab is illuminated by seven 100 watt bulbs placed behind glass covers. The electrical system is connected to a control panel with facilities for dimming the lights and also controlling on/off settings to simulate, for example, natural photoperiods (Suntracker, Paragon Electric Canada Ltd, 221 Evans Avenue, Etobicoke, Ontario, M8Z 1JS). The control panel also regulates a heater and Xpelair fan in the office and an air conditioner (Electrohome, 5,000 BTU rating) by on/off switch in the lab. An on/off switch for the air compressor which is housed in an adjacent shed is also provided.

The modified Vogel flume (#5) was used in the lab. until the end of July when the new Mini Flow Tank (#6) was installed. At this time the #5 flume was removed for storage and a 3' diameter round tank placed in the lab for experiments with salmon smolts (Fig. 7). There is a video camera system, data logger and PC with 10 separate relays in place connecting it and the flume wet lab.

A three-dimensional positioner constructed of Unislide Assemblies parts (Velmex, Inc., East Bloomfield, N.Y. 14443, U.S.A.) was made by the Mechanical Engineering group at the Bedford Institute of Oceanography. It carried velocity or temperature probes (up to four at a time) in custom made quick clip on/off assembles. The positioner fitted over the flume walls and could be secured with plastic screws. One hundred units on each of the Unislide knurled knobs was equal to 1 mm in slide movement.

FLOW VELOCITY

Velocity control in the Mini Flow Tank

Compressed air is supplied from a 10 H.P. Webster model 811-1 air compressor and pressure storage tank located in a small shed

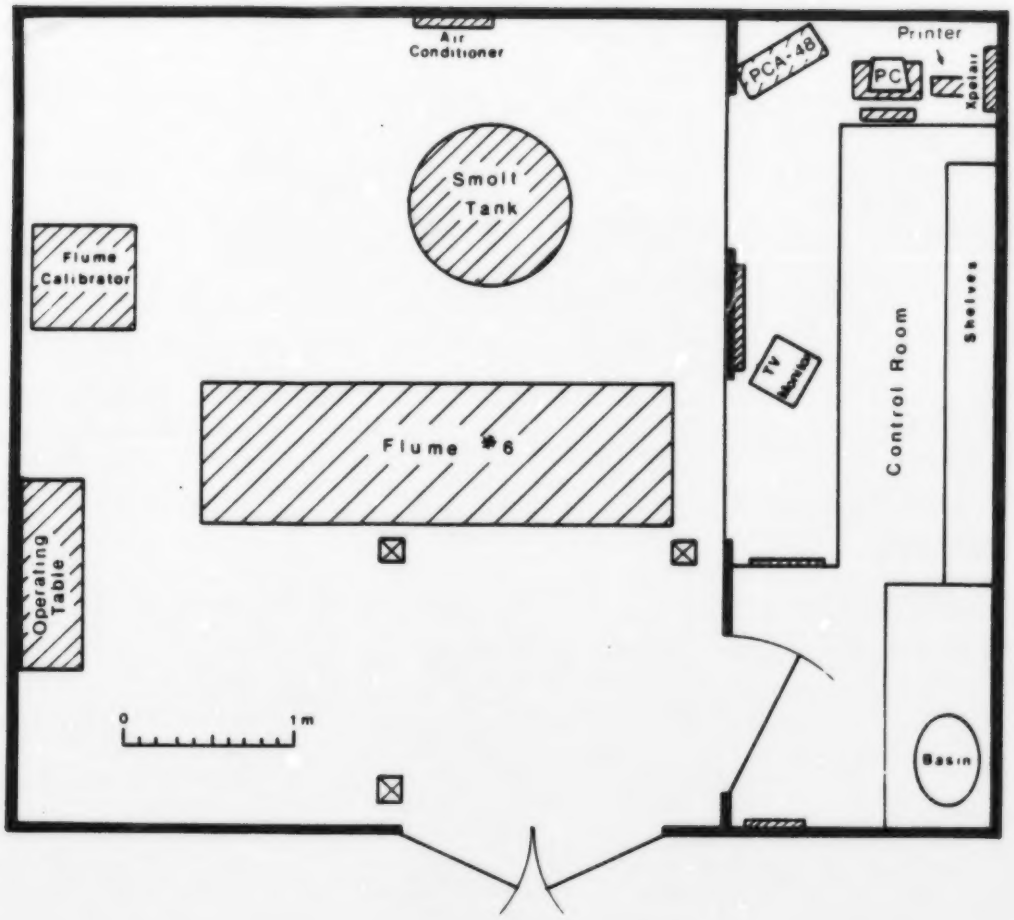

Fig. 7. Plan view of the St. Andrews Biological Station flow simulation laboratory in 1991.

close to the lab. The air is supplied in a 1/2" plastic pipe through a Wilkerson CBO-03-000 D90 air trap and pressures gauge (set at 70 psi) and oil lubricator (Wilkerson L16-04-000 K90) to the drive head of the impeller shaft. The settings on the threaded controller (throat valve) correspond to velocities as shown in Table 3. Exhausted air is carried in a second hose outside the building to waste.

Velocity calibrator

The apparatus was designed and constructed in the Chemical Engineering laboratory at the University of New Brunswick. It consisted of a 20-cm diameter acrylic tube and overflow tank (Fig. 8). Two in-line flowmeters (Blue White Industries, Westminster, CA, U.S.A.) could adjust the flow over the range up to 40 L/min (LPM) which is equivalent to ~32 $cm \cdot s^{-1}$. Sea water entered the tube at the bottom passing through flow forming elements and a 5-cm diameter exit hole before passing up the tube and over flowing into a tank and going to waste. Test probes were introduced at $\leq$1 cm above the exit hole in a rubber bung which had been sagitally halved and bored to take the probe diameter. It was necessary to ensure that the probe was positioned centrally above the exit hole, so that the Stream Flo probe was normal to the flow.

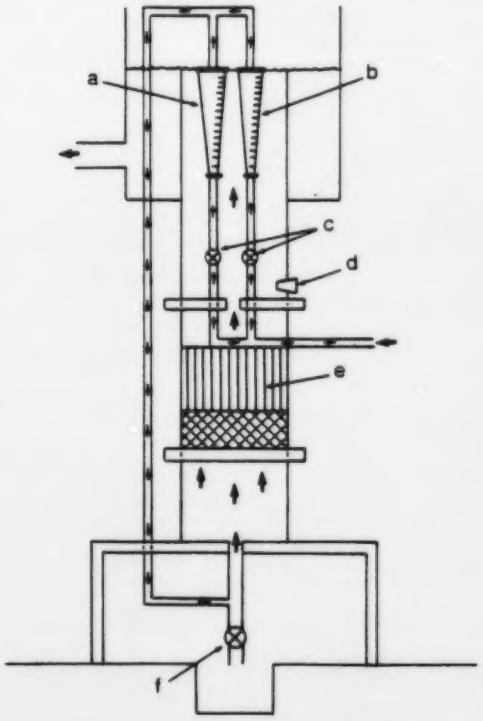

Fig. 8. Velocity calibrator. a. flowmeter CF45750 (4-40 LPM); b. flowmeter CF45500 (1.8-18 LPM); c. velocity control; d. test probe position; e. flow forming elements; f. seawater drain valve.

Velocity measurement

Two systems were available to measure velocities - Stream Flo velocity meters, and thermistor bead velocimeters.

The Stream Flo system is manufactured by Nixon Instrumentation, Charlton Kings Industrial Estate, Cirencester Road, Cheltenham, Gloucestershine, U.K. GL53 8 DZ. On hand are six model 403 probes (Numbers 896, 1329, 1330, 1473, 1474, 1487) and two model 412 digital indicators, 115v 60 cycles (Numbers 3066 and 3303). The model 403 probes are 46.8 cm long and have a rotor protected by a metal ring with projecting bars. The five-bladed, PVC rotor is on a hard stainless steel spindle mounted in conical pivots with a 1-mm Vee Jewel bearing. An insulated gold wire in the probe terminates at 0.1 mm from the rotor tips. During operation, the passage of the blades past the gold wire varies the impedance, causing the indicator current to generate a square wave signal whose pulse rate is proportional to the rotor speed and hence ambient velocity. The indicators have a 3-digit LED display in hertz (Hz). One-, 10-s or continuous sampling is possible for the indicator with output for a recorder (0-200 μA).

The rotor diameter is 11 mm and so integrates flow in an area of 95 mm^2. Because of the protective metal ring, the tips of the rotor can come only ~2.5 mm away from a hard surface.

Although Nixon Instrumentation provides a calibration chart with each model 403 probe, it has been found useful to regularly calibrate each probe in use because this helps to identify any problems in velocity measurement with it. I have found the Stream Flo system to be trouble-free to use, although macro particles in the seawater (e.g. hair, bivalve faeces) may interfere with the free turning of the rotor. We routinely view the rotor under a low power binocular microscope and remove foreign particulates with a fine pair of

forceps or by treatment in a sonic bath. After every use, the probe head is cleaned with 100% ethanol and rinsed with deionized water. Occasionally we have had trouble with faulty electrical connections, but this is usually obvious by the performance of the digital indicator.

The calibrator is used to check each model 403 probe weekly during regular use or at the beginning of new use of a probe. After turning on the seawater flow to the calibrator the probe is positioned in it as described on p. 11 and the flowmeters adjusted to a range of velocities (Table 6). The velocity (U) indicated by the calibrator in L/min (LPM) can be converted to $cm \cdot s^{-1}$ by:

$$U, cm \cdot s^{-1} = -0.0759 + 1.313 \times LPM - 1.26 \times 10^{-2} \times LPM^2$$

A plot of mean Hz on U (Fig. 9) is linear except below 5 $cm \cdot s^{-1}$. The quoted range of the 403 Stream Flo probe is 2.5-150 $cm \cdot s^{-1}$, although as mentioned the velocity calibrator can only determine velocities to a maximum of 32.28 $cm \cdot s^{-1}$. It is assumed that projections of the regression line beyond the upper limit of the calibrator give reasonable prediction of the 403 probes output in the higher range.

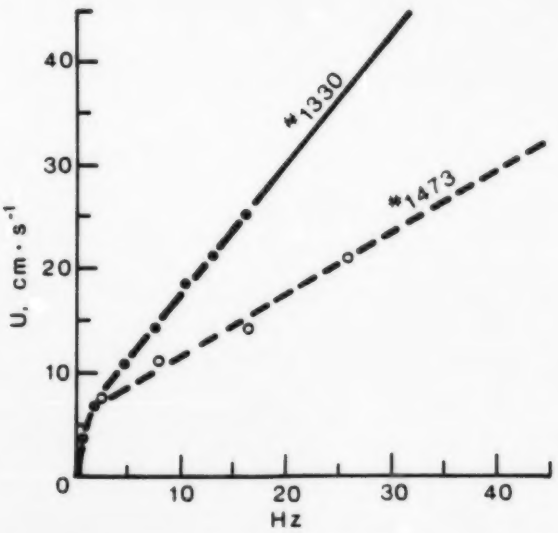

Fig. 9. Streamflow probe calibration plot.

Table 6. Calibration for Stream Flo probe #1330 using the 10 second integration option.

LPM	H_z	Mean H_z	Equivalent $cm \cdot s^{-1}$
3	1.2, 1.2, 1.0, 1.1, 1.2	1.14	3.6
6	2.5, 2.4, 2.5, 2.5, 2.4, 2.5, 2.5, 2.42	2.45	7.1
9	4.9, 4.9, 4.8,4.9, 4.8, 4.9	4.85	10.8
12	7.4, 7.5, 7.4, 7.5, 7.5, 7.6, 7.5, 7.6	7.5	14.0
20	13.4, 13.3, 13.14, 13.4, 13.3, 13.4	13.35	21.1
16	10.5, 10.5, 10.5, 10.5, 10.5	10.5	18.7
24	16.2, 16.1, 16.0, 16.1, 16.1	16.1	25.3
12	7.5, 7.7, 7.5, 7.6, 7.5	7.55	14.0
6	2.6, 2.5, 2.5	2.55	7.1
3	1.5, 1.0, 1.1, 1.0, 1.0	1.1	3.6

The thermistor bead velocimeter currently on hand was manufactured in the University of New Brunswick, Dept. of Chemical Engineering Fredericton, NB, E3B 5A3, from a design by Vogel (1981). The circuit diagram given on p. 312 of Vogel (1981) was followed (see also Kristmanson 1991) with minor modifications. The thermistor used was from the Victory Engineering Corporation, Springfield, New Jersey, U.S.A. 07081, Veco model #21A14 with sensing head diameter of 1.326 mm.

The equation used in the velocimeter calibration (from Kristmanson 1991) is:

$$U = \left[\frac{1}{\frac{\beta'}{\Delta V'^2} - \alpha} - 1 \right]^2 0.2912 \quad \text{.....(1)}$$

where U = velocity in $cm \cdot s^{-1}$
α = the probe constant
β' = a circuit plus probe constant
$\Delta V'$ = $a\Delta v_0 + b$, where the amplifier output is $a\Delta v_0$ and a and b are circuit parameters to be determined.

The coefficient 0.2912 was measured at a temperature of 7.8°C and a probe diameter of 1.326 mm - any departure from these parameters must be corrected for as in Kristmanson (1991).

It is necessary to determine a probe constant (α) for each new probe used (see Kristmanson 1991). For the probe currently available velocimeter probe #1 $\alpha = 1.5398$.

The thermistor bead probe was carried in a steel tube and during calibration this was mounted in the flume alongside a previously calibrated Stream Flo 403 probe so that both experienced the same velocity (e. g. equal height above the bottom) but did not interfere with the flow patterns of each other. The temperature compensating thermistor of the velocimeter was placed in the flume flow and sufficient time allowed for it to equilibrate.

The flume flow was reduced to 0 and when it had stopped circulating, the potentiometer was set so the micrometer indicates ~10 microamperes. The flume was then run at a low (5 $cm \cdot s^{-1}$) followed by a higher velocity (~15 $cm \cdot s^{-1}$) and voltage measurements across the external resistance made with a voltmeter (Fluke 87 True RMS multimeter, Fluke Electronics Canada Inc, 400 Briltania Rd. East, Unit #1, Mississauga, Ontario, L4Z 1X9) to 0.1 mV. The pen position (0-100) on a millivolt recorder (Brinkmann 2544, Brinkmann Instruments (Canada) Ltd, 50 Galaxy Blvd, Rexdale, Toronto, Ontario) was also noted with the linear mode operational. Using these data, the terms e and f are evaluated in:

$$\Delta V_1 = ed + f$$

where d is the number of recorder divisions.

The velocimeter probe was then compared with the Stream Flo 403 probe as standard (U, $cm \cdot s^{-1}$) in estimating β' in two ways:

$$\left(\frac{0.2912}{U}\right)^{1/2} = \frac{\beta'}{\Delta V_1^2} - \alpha \quad \text{.....(2)}$$

$$\beta' = \left[\left(\frac{0.2912}{U}\right)^{1/2} + \alpha\right](ed+f)^2 \quad \text{.....(3)}$$

If the values of (2) and (3) were within ±2%, the average value was used to calculate U by the equation (1). If the values are not close, a third determination is made and the worst value discarded.

The above calculations are made with a program written for an IBM compatible PC using the spread sheet Quattro Pro (Kristmanson 1991). Typical results with velocimeter probe #1 are shown in Fig. 10. The curvilinear response shows that velocities > 20 $cm \cdot s^{-1}$ cannot be measured by the probe because the response has peaked. The useful range for this probe is thus ~2 - 20 $cm \cdot s^{-1}$.

TEMPERATURE

It is important during flume experiments to maintain a constant seawater temperature so that this variable does not influence bivalve feeding rates.

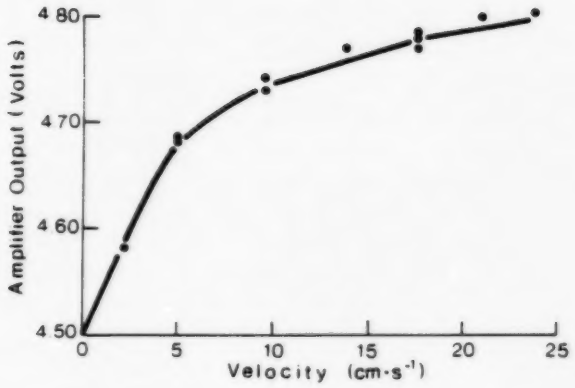

Fig. 10. Thermistor bead velocimeter #1 calibration plot.

Temperature control

In the new flow simulation lab, it was hoped that the air conditioner would maintain low enough wet lab air temperatures to avoid heating the flume water during 2 h long experiments. This proved not to be the case; for instance, in April, incoming filtered seawater was 4.5°C and during a 2-h experiment in the modified Vogel flume (80 L), it heated 2.5°C at a wet lab air temperature of 14°C.

The solution was an in-flume cooling coil of titanium supplied with circulating Freon from a remote source (so the pump motor did not interfere with acoustic measurements). The pump was controlled by a temperature regulating circuit (Appendix 3) designed and built by Laurence White of the NB Community College, St. Andrews. Cooled water could also be supplied to the flume from the overhead 1000-L capacity head tank which contained a refrigerated titanium cooling coil (Mini Cool).

Temperature measurement

A Hewlett Packard 2802 A thermometer (#1213 A06922) and temperature probe (HP 16642 - 2209 M) were mounted in the flume flow. The probe was 6 mm in diameter at the tip and 13 cm long. Calibration of this instrument was probe specific and required calibration of both digital and analogue outputs at 0°C by measuring the probe in a Dewar flask containing ice shavings and water. See the Hewlett Packard Thermometer System 2802-A operating and service manual for details.

SESTON

It is well established in the literature of the subject (e. g. Brand 1991) that feeding and growth are controlled by seasonal changes in the concentration and quality of seston as a food source.

Seston supply

In the flow-through, multiple-channel flume the seawater supplied is unfiltered natural seawater taken from bottom water near the end of the Station wharf and supplied to the flume before it is filtered. Hence, growth studies can be conducted to closely reflect the growth potential of natural local seawater for bivalves. Filtered seawater is usually employed in bivalve feeding experiments if cultured microalgae are added. Knowing the volume of seawater and the density of microalgal cells in the culture, it is possible to adjust the initial density of microalgae in the flume. The volume of cultured microalgae required is often quite large, e. g. to obtain a cell density of 10^6 *Chroomonas salinus* cells/L in the Mini Flow Tank; since the maximum culture density attainable is ~10^9 cells/L and the total volume in the flume = 200 L, we require 200 x 10^7 cells/L = 20 L x 10^9 cells. Thus we require all of the culture solution or 20 L to achieve the desired density. Local blooms of microalgae (e. g. *Nitzschia pseudodelicatissima*) reach maximum densities of 2.8 x 10^8 cells/L (Martin and Wildish 1990).

Microalgal culture methods employed are standard (see Guillard 1984) for easily cultured microalgae, such as *Chroomonas salinus*, although specialized techniques (or green thumbs) are required for some species (e.g. *N. pseudodelicatissima*).

Seston concentration

Two methods are routinely used in determining the concentration of microalgae present in the seston seawater samples. A fluorometric method involves extraction of chlorophyll a from the filtered sample and measurement in a Turner III fluorometer calibrated with known quantities of chlorophyll a. The other method involves direct microscopic

counting on a slide fitted with a counting chamber of known volume (haemocytometer of 0.01 mL capacity).

To measure chlorophyll a, take a seawater sample of appropriate and measured volume, and filter in a Millipore vacuum system with a Whatman GFC filter in place. Remove and fold the drying filter paper and grind in a mortar containing a few grains of sea sand and drops of 90% acetone. Pour the contents into a graduated centrifuge vial and make up to 10 mL with 90% acetone washings from the mortar. The vial is stored in the dark for a 2-h period before centrifuging for 5 min (half speed in an IEC clinical centrifuge). After diluting some of the supernate appropriately (usually 1:100) with further 90% acetone, the blank sample is ready for analysis. After warming up, the fluorometer is zeroed with a 90% acetone blank and the unknown sample read. The method is calibrated against pure chlorophyll a purchased from Sigma Chemical Co.

To measure cell numbers a small aliquot (5 mL) of seawater is removed from the flume and placed in a vial with a drop of formalin-acetic acid for fixing the cells. After thorough shaking, an aliquot is withdrawn in a Pasteur pipet and used to load the 0.01 mL capacity haemocytometer. With a Carl Zeiss microscope fitted with a Neofluar 25/0.60 objective and 8 x eyepiece, all cells in the 16 x 16 grid are counted. When 25 adjacent grids have been counted, the numbers are totalled and this equals cell number/mL x 10^4.

A recent calibration involving cell density (x) and chlorophyll a (y) content as µg/L (Table 7) yields a regression of:

$$y = 6.19E - 4x + 7.868,\ r^2 = 0.995,\ n = 28.$$

The mean of each of the x and y columns with the standard error as a percentage of the mean gives an estimate of the variability of each measure (Table 8). This analysis shows that the cell density measurement and chlorophyll a determination seem equally variable (standard errors < 1-5%) except in the most dilute solution analyzed for chlorophyll a (standard error of 11.3%).

Seston quality

No routine measurement of seston quality - by which ultimately is meant its ability to promote growth in a specified bivalve - is available.

During preliminary studies with filtration rate measurements of blue mussels at varying ambient flow velocities (Wildish and Miyares 1990), it was noticed that two major factors influenced the filtration rate of *Mytilus edulis*: velocity (with $r^2 = 0.45$) and initial chlorophyll a level (with $r^2 = 0.2$). Since the mussels were all offered the same initial cell concentration of a cultured microalga (10^4 cells•mL^{-1} of *C. salina*) and fed more rapidly on cells with higher chlorophyll a, the initial chlorophyll a per cell could be used as an indicator of the palatability (but not necessarily growth promotion capabilities) of that particular species of microalga. The mean initial chlorophyll a concentration used in our experiment was: 1.5 pg•cell^{-1} with 2X standard error as 7%. The actual range of levels recorded over 40 separate experiments was 0.72-1.84 pg•cell^{-1}. Although satisfactory if a unialgal culture is fed to bivalves, when a mixed culture or natural seston is offered, the method may become invalid. This is because different microalgae may have different quantities of chlorophyll a per cell or affect palatability (e.g. the presence of toxins resulting in differential ingestion). Despite this, MacDonald and Ward (1991), using mg chlorophyll a/mg seston in scallop feeding experiments, claim it to be satisfactory.

The question of food quality in freshwater and marine studies was considered at the 1991 annual meeting of the American Society of Limnology and Oceanography, held at St. Mary's University in Halifax. Bowen (1991), studying fish, thought that protein and energy contents were required to characterize the growth potential of food for *Tilapia aurea*. Enzymatically available protein has been proposed as a measure of the food of deposit feeding macrofauna (Meyer 1991) and the method could readily be used on seston pellets. Harrison and Thompson (1990) showed that the diatom *Thallassosira pseudonana* grown under enhanced light conditions produced better growth and survival rates of Pacific oyster larvae (*Crassostrea gigas*) apparently due to increased levels of carbohydrates in the cell.

Table 7. Cell density (x) and chlorophyll a content as µg/L (y) for a seawater dilution series of *Chroomonas salinus* culture.

Replication #	1:1,000,000 x	1:1,000,000 y	1:10,000 x	1:10,000 y	1:1000 x	1:1000 y	1:100 x	1:100 y	1:10 x	1:10 y	0 x	0 y
1	5.4	.0083	109	.0568	860	.6231	7800	8.374	79,000	83.74	1,220,000	705.2
2	5.2	.0061	105	.0568	800	.5901	7200	8.925	76,000	80.43	1,190,000	762.5
3	6.1	.0061	89	.0623	860	.6231	7200	8.594	76,000	79.33	1,220,000	727.2
4		.0094	98	.0557	1010	.6121	7600	7.713	73,000	81.53	1,210,000	793.3
5			112	.0169	1030	.6341	7300	7.602	86,000	81.53	1,200,000	785.3

Table 8. Mean cell density (x) and chlorophyll a content (y) with standard error (SE) as a percentage of the mean.

Dilution	x ± % SE	n	y ± % SE	n
0	$1.208 \times 10^{6} \pm 0.5$	5	754.68 ± 2.2	5
10	$7.800 \times 10^{4} \pm 2.8$	5	81.31 ± 0.9	5
10^{-2}	$7.420 \times 10^{3} \pm 1.6$	5	8.24 ± 3.1	5
10^{-3}	$9.120 \times 10^{2} \pm 5.0$	5	0.617± 1.2	5
10^{-4}	$1.030 \times 10^{2} \pm 4.0$	5	0.059± 2.4	5
10^{-5}	5.570 ± 4.9	3	0.008± 11.3	4

VIDEO CAMERA

The video camera system available consists of:

- an RCA TV camera (TC2855C) with a zoom lens (12.5-75 mm, from Cosmicar, Model C621218M3-2),
- a remote lens controller (from FOR-A Co, model M2-6B),
- an Electrohome video cassette recorder, and
- two black and white Rostech video monitors, one in the wet lab and the other in the control room.

The equipment was ageing and surplus to the requirement of the now defunct BRUTIV (Bottom Referencing Underwater Towed Instrument Vehicle) development project at the Biological Station.

Use of the camera has clearly demonstrated the utility of a video system in bivalve feeding studies. In our June/July studies of giant scallops in the modified Vogel flume (Fig. 11), the camera was focused on the exhalant opening while flow rates were varied. Scallops are very sensitive to light changes but by screening one side of the flume it was possible to adjust flows without disturbing the scallops. Exhalant opening areas could then be monitored on undisturbed scallops by making measurements directly on the screen. These results provided the first evidence that the degree of opening of the exhalant was directly related to the ambient velocity (Wildish and Saulnier, in press).

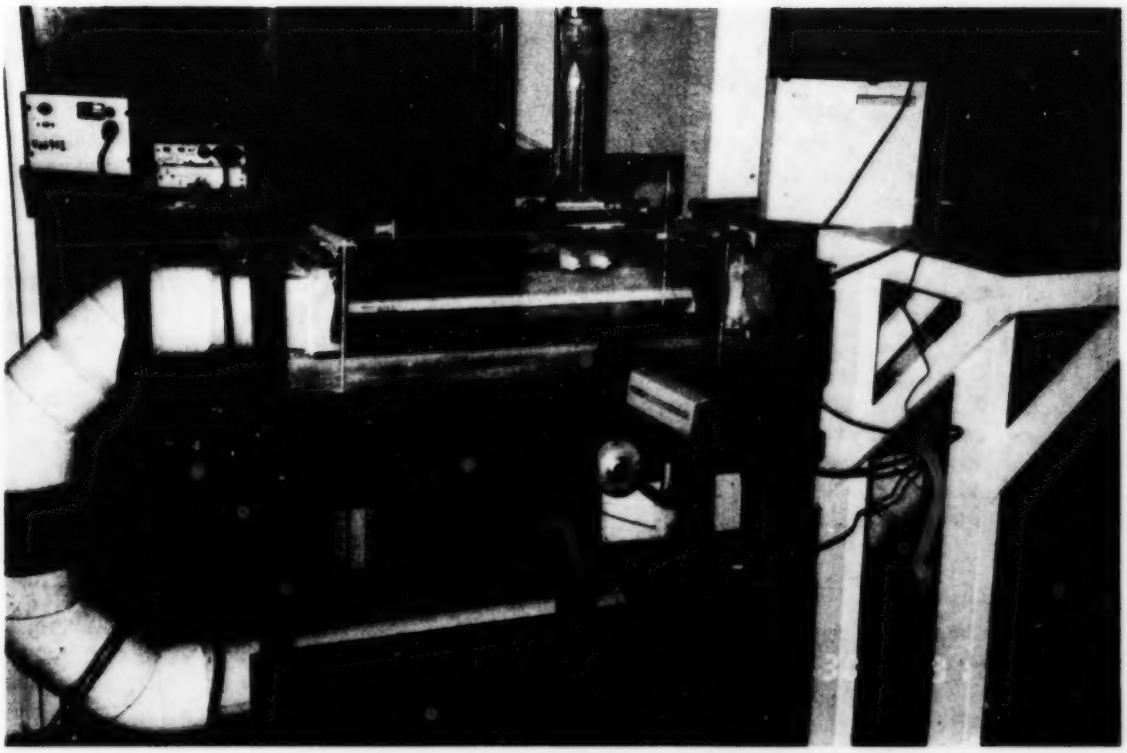

Fig. 11. Experimental setup for June-July 1991 with the Vogel flume to determine the mechanism of velocity in giant scallops.

DATA LOGGING AND ANALYSIS

The data logger was obtained from Alpha Controls and Instrumentation, 361 Steelcase Rd., West, Unit 3, Markham, Ontario, L3R 3V8 and consisted of:

- PC A-48 Aquistor to handle up to 48 input channels of 0.3 microvolts to 10 volts.
- Options obtained include: menu-driven software, signal conditioning (to provide temperature referencing and linearizing for thermocouples), printer-driver (to give real time printout), multi-tasking software (to allow simultaneous use of the PC while it is recording input data from experiments), a 10 relay output (for control of equipment by the PC Aquistor), RS-232 serial interface and high speed data storage facility.

The personal computer (PC) used with the data logger was an IBM compatible, with $3^1/_2$ and $5^1/_4$" disk drives, a 40 meg hard disc and 1 meg of memory. The multi-mode printer was a Panasonic KX-P1180.

PREPARATION OF BIVALVES AS EXPERIMENTAL ANIMALS

Bivalves are preferably collected by hand, ie. at low tide by digging for clams or by removal from rocky surfaces as in the case of blue mussels. For giant scallops, this means collection by SCUBA divers, although we have also used undamaged scallops collected by dredging. In transporting the bivalves back to the lab, the aim is to avoid temperature shocks and preferably to keep them in running seawater at ambient seawater temperature.

Once back at the lab, the bivalves were immediately transferred to holding conditions where they experience low current velocities and natural seston concentration and quality. They were held either in lantern nets suspended from the Biological Station wharf pontoon, or placed in

the multichannel flume through which non-filtered seawater was flowing at ~5 $cm \cdot s^{-1}$.

For the purpose of flume holding, the three wall dividers were removed as well as the two fine mesh screens which tend to clog up during use. Calculations were made (i.e. assuming adult sized scallops pump 10 $L \cdot h^{-1}$, and adult blue mussels 2 $L \cdot h^{-1}$) to ensure that a downstream seston depletion effect was absent with the densities present.

Individual bivalves of adult size can be identified by attaching a small, numbered plastic tag (available from Hallprint Pty Ltd., 27 Jacobson Crescent, Holden Hill, South Australia 5088, Australia) with a cyanoacrylate adhesive that is available from Satellite City PTO, P.O. Box 836, Simi, California, 93062, USA.

The feeding history must be known before experimentation involving bivalve filtration feeding. This is usually achieved by starving the bivalves for 24-48 h by placing them in a holding tank receiving filtered seawater. In growth studies which are of longer duration (few weeks or more versus few hours for feeding), the feeding growth history is less critical, although definitive growth studies will require this knowledge.

FLOW SIMULATION LAB: THE FUTURE

It is difficult to predict how the lab will be set up next year, let alone in 5 yr time. Nevertheless, there are some obvious improvements to methods used in the present system as described in the previous sections (short-term improvements for which solutions appear to be available) as well as novel objectives and/or improvements for which solutions seem to be less clear (long-term improvements).

METHODOLOGY IMPROVEMENTS

An obvious improvement to the flow calibrator is to provide it with flowmeters which increase its velocity capability to the upper range achieved by the Mini Flow tank. Flowmeters can be purchased and, as long as there is sufficient pressure in the system, should enable the higher velocity to be directly calibrated.

For the reasons mentioned in the appropriate section, the measurement of seston quality by chlorophyll a per cell or per unit weight of seston are unlikely to be sufficient for many future uses. Hence, a method should be calibrated which will compare protein:carbohydrate or chlorophyll a:carbohydrate contents in sestonic food of known dry weight.

Improvements required for the video system include: replacement of the VCR system to provide a better cassette editor so that stopped images can be analyzed for shape, area, and number, a video digitizing board and software for the PC to enable automated analysis of shapes, area, etc.

LONG-TERM IMPROVEMENTS

One goal of the last few years has been to devise an automated system for adding cultured microalgae to the flume in such a way that the rate of addition is a direct indication of the feeding rate of a single bivalve or group of bivalves. Winter (1973) originally used such a system in a gently stirred tank (10-L capacity) containing a group of blue mussels. A photometric system was used to detect the loss of light caused by absorption by the microalgae present. By suitable relays and switches, it was possible to have the increasing light level (caused by the bivalves consuming the microalgae) switch on a dosing valve connected to a microalgal culture kept suspended by a magnetic stirrer. This system was not specific since any particles present would reduce the light reaching the photoelectric cell, and hence could not be used with natural seston in seawater. Modern liquid particle monitoring systems (i.e. that produced by Met One, 481 California Avenue, Grants Pass, OR, 97526, USA) do not seem adaptable to this purpose (J. Hunt, pers. commun.) for the same reasons.

The ideal solution seems to be in flow cytometry because this technique simultaneously measures cell volume, density, and the fluorescent properties of the microalgae present. With this method it should be possible to identify individual species of microalgae in a complex, natural, seawater sample. Because of the high initial cost of the flow cytometer, it has not been considered for use in the flow simulation lab.
A cheaper and somewhat less satisfactory method is by flow fluorometry, in which the

natural fluorescence of microalgae is directly monitored (Fig 12). Limitations of this method are currently being investigated, in particular the high concentration quenching and/or absorption of light by the microalgae. Bayne et al (1977) have used flow fluorometry to measure feeding rates of blue mussels; the method was satisfactory with monoalgal cultures but not with

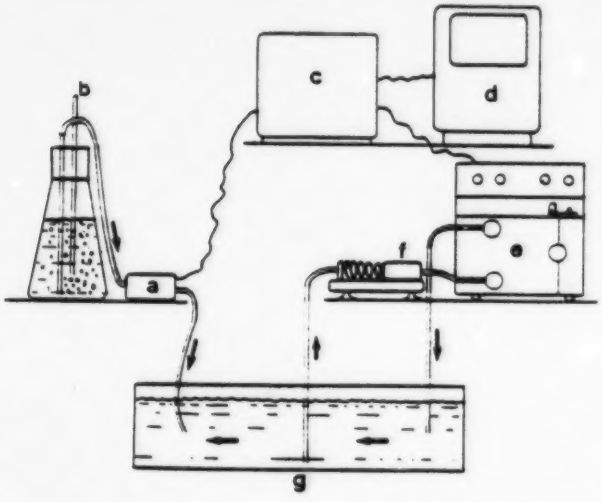

Fig. 12. Possible setup for a flume with automated addition of microalgae to monitor bivalve feeding rates. a. metering pump controlled by c; b. aerator to mix microalgal culture; c. data logger with switch relays; d. microcomputer; e. Turner flow fluorometer; f. sampling pump.

natural phytoplankton in seawater. The Turner filters used are a primary 5-60 and secondary 2-64 giving excited light at 430 nm and emitted light at 650 nm. Provided the flowmeter is sufficiently sensitive to measure small changes in fluorescence (maximum of 0.04% per min^{-1}) based on one scallop filtering with 100% efficiency at 10 $L \cdot h^{-1}$ in a total of 200 L throughout the experiment, it will be necessary to add a stock microalgal culture (= initial concentration) at 75 $mL \cdot min^{-1}$. If the stock microalgae culture is 10x more concentrated, its addition rate can be reduced to 7.5 $mL \cdot min^{-1}$.

Future objectives are to run feeding experiments with natural microalgae collected beforehand in a plankton net or in a newly designed continuous collecting device. The microalgae could be metered into the flume by the automated method outlined above with the rate of addition indicating the effect of known harmful microalgae on bivalve feeding rate.

It is also hoped to study salmon smolt physiology and behavior challenged by toxic microalgae using an implanted ECG monitor which has been developed. Experiments are planned in which the smolts are exercised by exposure to controlled velocities. This will require construction of a larger flume of 1000 L capacity (the maxi flow tank #7) based on the present Mini Flow Tank design.

An immediate future requirement in bivalve growth studies is that the experimental subjects should be of known genetic stock. With the recent development in many parts of the world in culturing bivalve spat and the development of successful methods to grow them out to juvenile stage in commercial hatcheries this is already feasible.

DISCUSSION

The St. Andrews Biological Station is ideally situated to support a flow simulation laboratory because of the high quality of the locally available, St. Croix estuary seawater. There is a general lack of industrial activity, apart from forest industry-related (i.e. saw and pulp mills) and absence of intensive agriculture throughout the St. Croix River catchment. High seawater quality is one reason why a United States group of investors, in 1991, began investigating the feasibility of a land-based salmonoid culture facility at Robbinston, Maine, just across the estuary from the Biological Station. The facility would include seawater grow out of smolts in raceways.

There is growing evidence that tidal currents, as flow direction and velocity, are fundamentally important in shaping both the type of benthic community and the production of suspension-feeding members of the community (e.g. Wildish and Peer 1983). It is not surprising therefore that other levels of biological organization, such as the behavior and physiology of suspension feeders are profoundly affected by flow direction and velocity. Nor is the effect of flow on benthic ecology limited to the esoteric since practical fisheries or aquaculture problems (ie. how to predict the carrying capacity of an area for blue mussel culture) or ecological

problems (ie. predicting changes caused by tidal power development) requires this knowledge.

In fact, a wide range of questions, at many levels of biological organization and with a diverse range of taxa, can only be solved by use of flow simulation experiments. Anyone interested in this field - animal experimentation involving flow simulation methods - is encouraged to contact the author.

ACKNOWLEDGMENTS

My interest in benthic biology led me into some unfamiliar areas of the physics of flow. I was very fortunate in having Professor David Kristmanson, Department of Chemical Engineering, UNB, Fredericton, NB as my guide and teacher in this field. David has collaborated directly in many of the experiments, been patient when "I was slow, thinking in broken images", and any scientific rigour in our work regarding the physics of flow is due to his insistence that the biology must fit the physics (and not the other way round).

The Biological Station workshop has talented people able to transform plans into reality. Many of the earlier flumes (#1-4) were made under the direction of Herb Small (retired 1987). Latterly, Brian Kohler was responsible for construction of the new flow simulation lab and refurbishing the multiple channel flume and its building . Flume work also requires pipes and fittings; and expert advice and craftsmanship were always available. Initially this was from Art Carson (retired 1987) and now from his son Richard Carson. Many of the measurements and observations in the flow lab are made with electronic equipment and I have relied on assistance from Sam Polar when problems arose. Sam was also responsible for the design of the electrical circuits and fittings in the new flow lab. It is a pleasure to acknowledge the help received from Mark Chin Yee (#6 flume) and George Steeves of the Management Services Branch, Bedford Institute of Oceanography, Bedford, NS, in getting the new lab equipped and running.

I wish also to acknowledge the expert technical assistance provided by Ms. Aline Saulnier (nee Decoste) and Ms. Michelle Ringuette in many of the experiments described in the papers included at the end of the reference list. Aline has worked with me for 9 yr and Michelle for 4 yr. I thank Ms. Jennifer Martin for help and advice in cultivating microalgae and Art Wilson for assistance in field collection of bivalves. Frank Cunningham prepared the figures for this publication and, over the years, he and Bill McMullon (retired 1991) have provided excellent graphics facilities both for publications and illustrated talks. I wish to thank Brenda Best and Elaine Maillet who prepared this publication for printing and Drs. Richard Peterson and Shawn Robinson for critically reviewing an earlier version.

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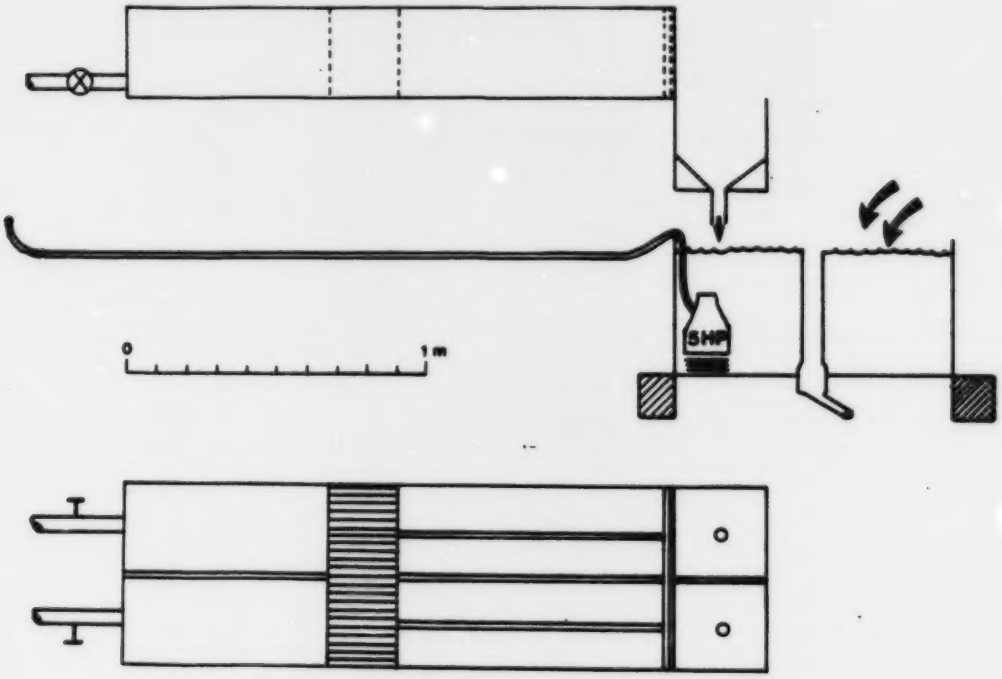
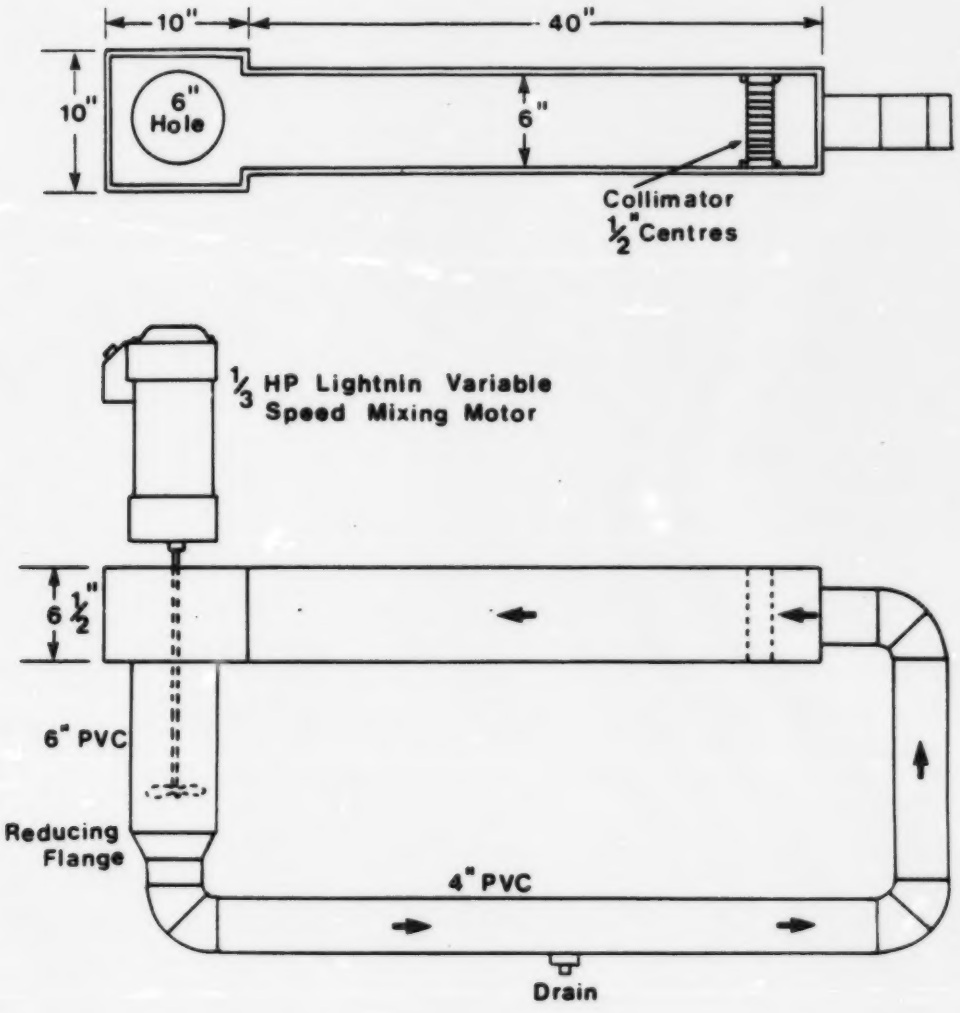
APPENDIX I. Recirculating flume for suspended sediment studies. Upper - side view, lower - plan view. Flume channel flow was from left to right.



APPENDIX II. Recirculating flume designed to replace the Vogel flume.



APPENDIX III. Parts list and wiring diagram of the cooling system used in the Mini Flow Tank.

Condensing Unit		Copeland Unit Model MGBH00205AA2
Compressor	C	Compressor Model ARD10020 SAA200 S/N 91B031949
Evaporator		12 ft 5/8" titanium
Metering Device		Alco balanced port thermostat Expansion valve BF1/4FC
Temperature Control	TC	Penn digital thermostat Model A350 Johnston control
	LV	c/w Penn low voltage (24V) power pac Model Y350 Johnston control
Low Pressure Control Protection	PC	Ranco low pressure Model 010-1402